Frequency-converted, polarization insensitive, and dispersion immune photonic link with Brillouin amplification

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ABSTRACT

We demonstrate a novel photonic link that simultaneously achieves frequency conversion, optical amplification, polarization sensitivity elimination, and fiber dispersion effect minimization. The link also uses low loss and less expensive phase modulators to replace amplitude modulators and thus eliminates modulator bias problems.

optoelectronic oscillator
OEO
photonics
oscillator

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Presently, most RF photonic links simply use optical waves as carriers to transport RF signals through optical fibers to remote locations. Other RF communication functions, such as signal generation, signal up/down conversion, amplification, and filtering, are still done in the electrical domain, although it has been shown that these RF functions can also be accomplished optically [1-5]. These simple photonic links, although necessary for introducing and fitting photonic technology into the existing RF infrastructure, do not utilizing the full potential offered by photonics. As photonic technology is more accepted in the RF world, sophisticated photonic links that are able to perform multiple signal processing functions become increasingly desirable.

We have demonstrated previously a technique called Brillouin selective sideband amplification (BSSA)[6,7] for photonic RF signal amplification and signal processing. In this paper, we describe a simple and elegant scheme that utilizes the BSSA to eliminate many practical problems and make multi-functional photonic links feasible. In particular, we demonstrate a frequency down/up conversion photonic link that has no polarization sensitivity, no need for biasing the modulators, no fiber dispersion induced signal fading, increased optical power handling capability, built-in optical amplification, and increased signal conversion efficiency.

As illustrated in Fig. 1, light from signal laser first passes through a modulator and is modulated by a local oscillator (LO) signal. The modulator can either be an amplitude modulator or a phase modulator. The phase modulator is preferred because it is easier to make, has lower loss, and needs no bias. The LO modulated signal light is then coupled into a standard single mode fiber through a polarization beamsplitter (PBS1) whose passing axis is aligned with the polarization state of the signal light.

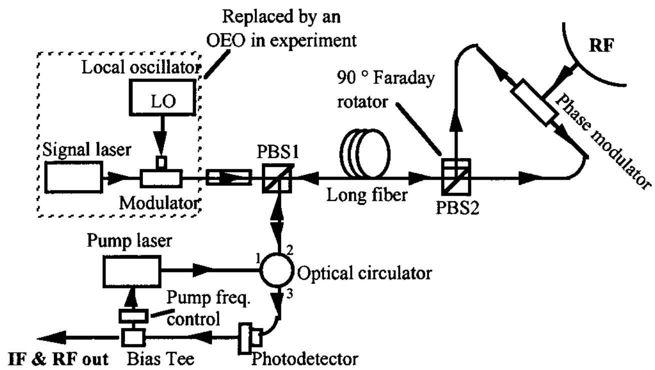

Fig. 1

After transmitting to the remote site through the single mode fiber, the polarization state of the signal light is no longer linear and varies when the fiber is disturbed. A second polarization beamsplitter (PBS2) is then used to separate the two polarization components of the signal light into two paths. A 90° Faraday rotator is placed in one of the paths to rotate the polarization state of light in the path. The two output ports of PBS2 are pigtailed with polarization maintaining (PM) fibers and the polarization component in each port is aligned with the slow axis of the corresponding PM fiber. The two PM fiber outputs are then connected with the two PM fiber pigtails of the phase modulator from opposite ends. The light beams passing through the phase modulator are automatically recombined by PBS2 and coupled back into the single mode fiber. Because the oppositely travelling light beams have the same polarization direction in the modulator, they are equally modulated by the RF signal. Consequently, this PBS/modulator ring arrangement eliminates the polarization sensitivity of the modulator [8].

Because of the 90° Faraday rotator in the modulator ring, the polarization state of the backward-going light beam in the fiber is orthogonal to the polarization state of the forward-going light beam at every point in the fiber. Finally, the backward-going beam is separated into port 3 of PBS1 and is directed to the photodetector via an optical circulator. The photodetector is immediately connected to a bias tee which separates the low frequency and high frequency (IF, RF, and LO) components of the received photocurrent. As will be discussed later, the low frequency component is used to lock the frequency of the pump laser to an intended modulation sideband of the signal laser.

On the other hand, the pump beam is directed to enter port 3 of PBS via the circulator. The polarization of the pump is so adjusted that the pump beam exits port 2 of PBS1 and enters the single mode fiber. After passing through the PBS2/modulator ring, the pump beam is fed back into the single mode fiber and enters port 2 of PBS1. Because of the action of the ortho-conjugator ring, the polarization state of the backward-going pump beam is orthogonal to the forward-going pump beam everywhere along the fiber. Finally, the pump beam exits port 1 of PBS1 and is attenuated by the isolator.

It is important to note that the forward-going pump beam always has the same polarization state of the backward-going signal beam, which allows optimized Brillouin amplification everywhere along the fiber and eliminates polarization sensitivity of the Brillouin amplification process [9].

It also important to note that almost all devices in the setup have multiple functions. The pump laser is used both for Brillouin signal amplification [6] and for phase to amplitude modulation conversion [7]. The latter permits the use of phase modulators in the system. The two functions of the first modulator are to generate LO subcarrier and to reduce the unwanted Brillouin scattering of the signal light. The polarization beamsplitter, PBS1, is used first to combine the signal and pump beams into the single mode fiber, and second to direct them into difference paths after they return from the remote site. Even the single mode fiber is used both as a signal transmission medium and as a gain medium for Brillouin amplification. Finally, the ring arrangement at the remote site, including PBS2, the Faraday rotator, and the phase modulator, has three functions: 1) returning modulated RF signal, 2) making modulator polarization insensitive, and 3) making Brillouin amplification polarization insensitive.

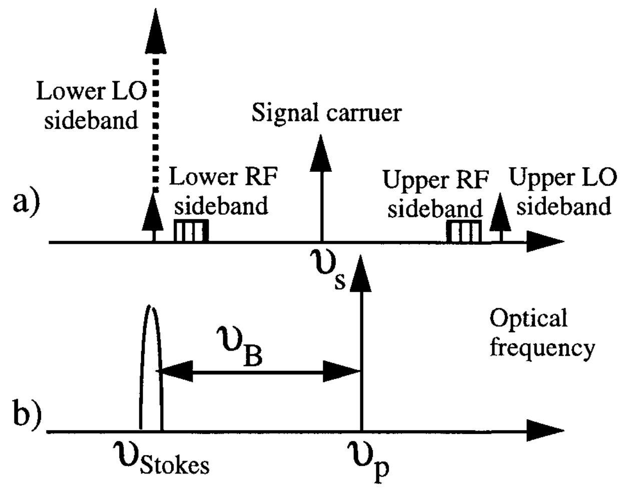

Fig. 2

To further simplify the link, we use an opto-electronic oscillator (OEO)[5] in the experiment to replace the local oscillator, the modulator, and the signal laser, as shown in Fig. 1. The OEO directly generates a stable and spectrally pure 10 GHz subcarrier that can be used for frequency down/up conversion. The phase noise of the OEO output was measured to be –140 dBc/Hz at 10 kHz away from the carrier. Fig. 2A and Fig. 2B illustrate the optical frequency spectra of the OEO, the pump laser, and the Stokes frequency of the pump laser's Brillouin scattering. By tuning the frequency of the pump laser, the frequency of the backscattered light (or the Stokes frequency) can be made to overlap with one of the phase modulation sidebands of the signal beam to amplify the sideband. The amplification of this modulation sideband will break the perfect amplitude balance of sidebands of a phase modulation and cause the phase modulation to convert to an amplitude modulation[7].

One may either amplify a LO sideband or a RF sideband to obtain amplified IF and RF signals at the receiver. However, amplifying the LO sideband has the advantage of having wide amplification bandwidth and signal conversion bandwidth.[6] On the other hand, amplifying a RF sideband generally results in higher gain, assuming that the RF sideband is weaker than the LO sideband. When the lower LO sideband is amplified by BSSA process, the beats of the amplified LO sideband with the lower and upper RF sideband in the photodetector produce down-converted and up-converted IF signal respectively, while the beat between the amplified LO sideband and signal carrier produces amplified LO signal.

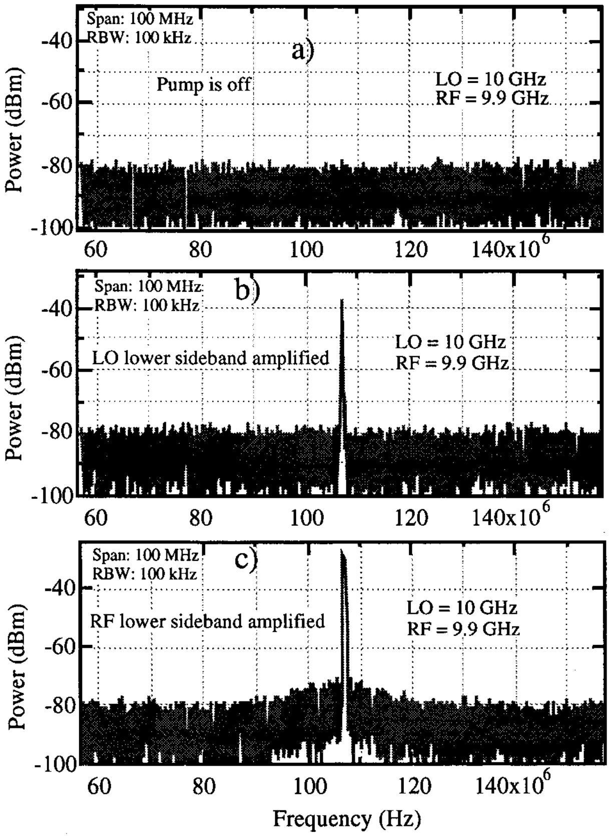

Fig. 3

In the experiment, the RF and LO frequencies were chosen to be 9.9 GHz and 10 GHz respectively and the expected down converted signal should be at 100 MHz. Fig. 3A illustrates that without BSSA present (pump laser was turned off), no down-converted signal at 100 MHz was detected. However, when the pump laser was turned on and tuned to amplify the lower LO sideband, the down-converted signal at 100 MHz was immediately detected and the result is shown in Fig. 3B. Similarly, when the pump laser's Stokes frequency was aligned with the RF lower sideband, the 100 MHz down–converted signal was also detected, as shown in Fig. 3C.

With the experimental setup of Fig. 1B, the stimulated Brillouin scattering (SBS) threshold was measured to be 15 mW. However, BSSA has no threshold and significant signal amplification and down-conversion was observed even when the pump power was much lower than the SBS threshold. Fig. 4A illustrates the IF power as a function of pump power when the lower LO sideband was amplified by the BSSA process while Fig. 4B shows both the RF and IF power as a function of the pump power when the lower RF sideband was amplified. It is evidence that only a few milliwatts of pump power would sufficiently amplifies LO or RF sideband and hence converts signals from RF to IF.

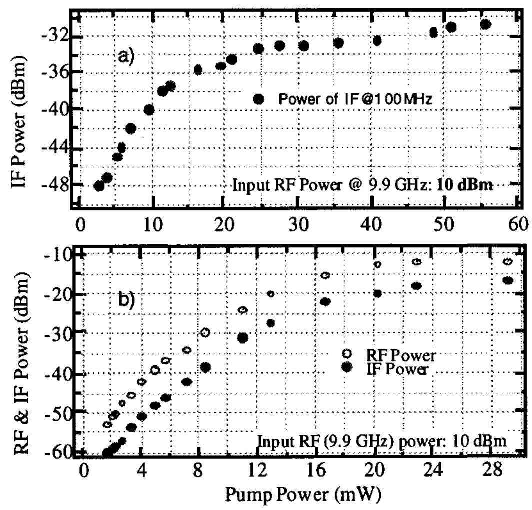

Fig. 4

In summary, we demonstrated a simple and elegant multi-functional antenna remoting link that simultaneously accomplishes signal up/down conversion, optical amplification, polarization sensitivity elimination, and minimization of fiber dispersion induced signal fading. In addition, the link uses phase modulators to replace amplitude modulators and eliminates the needs for modulator biasing and bias stabilization. Finally, a low phase noise OEO was used in the link to directly generate a LO subcarrier for frequency conversion.

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